

FINAL TECHNICAL REPORT

Iowa Photovoltaic System Case Study

Pond Circulation Application

Prepared for



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BLACK & VEATCH

**11401 Lamar Avenue
Overland Park, Kansas 66211
Tel: (913) 458-2000
www.bv.com**

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Principal Investigators:

Anand Pattani, Project Manager
Nate Lindstrom
Jason Abiecunas
Chris Helberg

Acknowledgments:

Pumps Systems: Mr. Joel Bleth, Mr. Mike Christensen, Mr. Harvey Hibi
Indian Health Services: Mr. Roger Eberhart

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Introduction and Executive Summary

The Iowa Department of Natural Resources (DNR) awarded a contract to Black & Veatch to develop technical case studies for four photovoltaic (PV) applications installed since 1999 in six Midwestern states - Iowa, Illinois, Minnesota, Wisconsin, Missouri and Nebraska. The purpose of these case studies is to independently demonstrate and verify the reliability and viability of photovoltaic systems.

Efforts were made to choose case studies that were diverse in applications and geographic locations. Black & Veatch prepared a questionnaire (Appendix A) and contacted various manufacturers, installers and owners of photovoltaic systems. The key aspect in choosing applications for the various case studies was availability of elaborate project information and production data. The following case studies were selected from a variety of applications:

- Crandon, Pulaski and Oshkosh-West Public Schools - Wisconsin
- Sac & Fox Indian Settlement Pond Circulator - Iowa
- Ciernia Home - Minnesota
- Kreitman Ranch Water Pumping - Nebraska

This document presents the Iowa case study. The Sac & Fox Indian Tribe wastewater treatment facility had problems of odor from high levels of total suspended solids (TSS) and biological oxygen demand (BOD) caused by water stagnation. The facility decided to install a pond circulation system to treat the odor problems. Pump System Inc. (PSI) designed and installed four solar pond circulator systems at the facility at a cost of \$92,100. Each system circulates up to 2,500 gallons per minute (5.57 ft³/s or 0.158 m³/s). The installed systems not only eliminated odor and provided cleaner effluent at the facility but also resulted in significant energy and emission savings.

Black & Veatch collected information on project timeline and history, design, procurement and installation process, operation and maintenance costs, production data and conducted an analysis on energy and emission savings. The results are presented in the next section.

Sac & Fox Indian Settlement Pond Circulator – Iowa Photovoltaic System Case Study

Project History

In 1999, Sac & Fox Tribe Waste Water Treatment Facility (WWTF) was operating beyond the capacity of its lagoon systems. This resulted in odor and inconsistent carbonaceous biological oxygen demand (BOD) reduction problems, which were exacerbated by the presence of a casino nearby. The WWTF plans to construct a larger mechanical treatment plant by April 2003. However, in the interim, the WWTF decided to use solar pond circulators to reduce the BOD and total suspended solids (TSS). Pump Systems Inc. (PSI) of Dickinson, North Dakota designed, manufactured and installed the pond circulators. The WWTF expects to use the solar pond circulators in conjunction with the mechanical treatment plant after April 2003.



The pond circulators, powered by solar PV panels, helped the Sac & Fox Tribe keep in compliance with the Environmental Protection Agency (EPA) and its discharge limits. Indian Health Services (IHS), an agency within the U.S. Department of Health and Human Services responsible for providing federal health services to American Indians and Alaska Natives, coordinated the procurement and design of the system.

IHS initially leased four pond circulators for a year and bought the systems at the end of the lease. The pond circulators reduced the odors in two to three weeks, and virtually eliminated them after two months.

New permits were not needed for system installation at the already existing facility. Since the system was off-grid, negotiations with electric utilities also were unnecessary.

Operating Philosophy

The floating solar-powered pond circulation machine (called SolarBee[®] since September 2001) reduces odors by increasing dissolved oxygen content of the pond water. This dissolved oxygen reduces BOD and destroys hydrogen sulfide odors created in the anaerobic zone at the bottom of the pond. The SolarBee[®] achieves this by drawing water from the lower

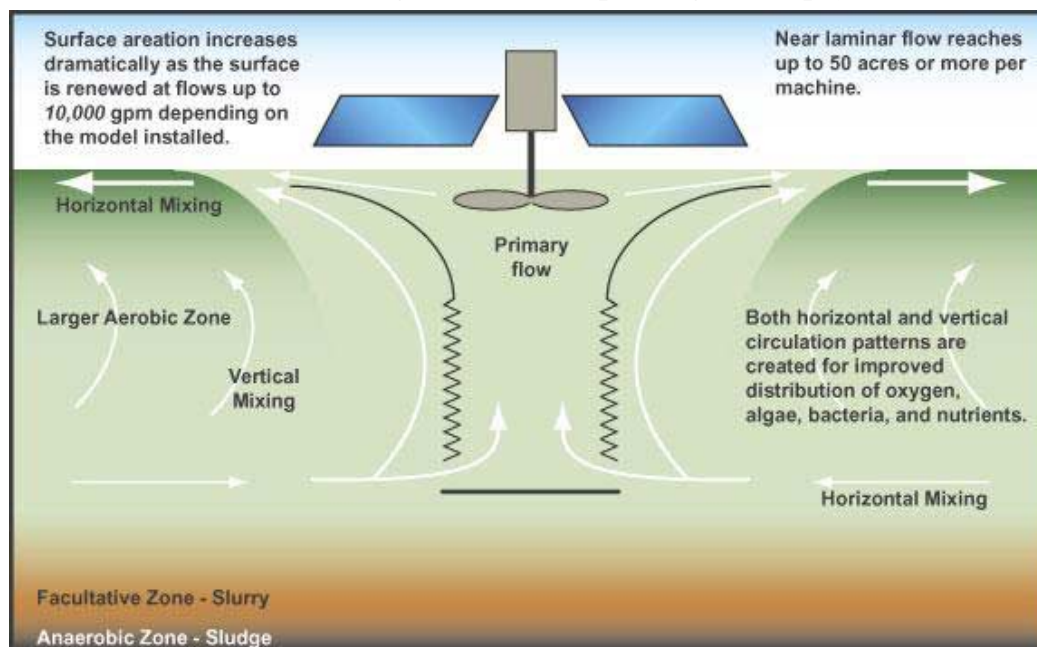
depths of the pond and spreading the water across the surface of the pond in a laminar flow pattern.

The complete system includes three 60 Watt (204.8 BTU/hr) solar panels, an electronic controller, high-density polyethylene floats, anchors, a draft tube, and an impeller and rotating assembly. PSI selected four pond circulators (SolarBee® SB2500) for the application at the Sac & Fox Tribe WWTF, the only model in production at the time.

The WWTF facility consisted of three lagoons. Raw wastewater is pumped to the first lagoon where waste is partially treated. The wastewater then flows to the second lagoon by gravity feed and after further treatment, to the third lagoon also by gravity feed. Since the water quality, measured in terms of odor, BOD and TSS levels, improves at every stage, it can be discharged from the third lagoon to the effluent stream. As per the design, PSI placed two pond circulators in the first lagoon and one each in the second and third lagoon. Each pond circulator used at the WWTF was designed to cause mixing at flow rates of up to 2,500 gallons per minute [gpm] (5.57 ft³/s or 0.158 m³/s) during peak sunlight. This high flow rate accelerated the biological processes within the pond.

Figure 1 illustrates the general operating philosophy of all SolarBee® pond circulators.

Figure 1: Iowa - Operating Philosophy



Design and Procurement Process

PSI considered the following factors in the design of the pond circulation system: existing system and design, level of BOD loading into the system, energy cost of aeration as an alternative, discharge permit levels, future needs and primary goal, which, in the case of the WWTF, was the reduction of odor.



The WWTF lagoons did not have any electricity at the site. IHS selected solar powered circulators designed by PSI because they did not need an electrical hook-up, and they were proven to mitigate odor problems.

PSI used the operating conditions shown in Table 1 to size and design the pond

circulator system at the WWTF lagoons:

Table 1: Iowa - Lagoon Operating Characteristics

Characteristics	Primary Lagoon	Secondary Lagoon	Tertiary Lagoon
Operating depth of lagoon, feet	5	6	6
Operating volume of full lagoon, cubic feet	1,477,587	850,641	865,102
Operating surface area of lagoon, sq. feet	384,635	170,755	170,755
Estimated inflow, ft ³ /s	0.348	0.348	0.348
Calculated dissolved oxygen needed to meet summer BOD reduction goal, lbs/day	289	43	11
Calculated dissolved oxygen needed to meet winter BOD reduction goal, lbs/day	261	37	9
Estimated dissolved oxygen each circulator can produce based on surface area, lbs/day	1660	736	736
Number of SolarBees [®] actually installed	2	1	1

Although one SolarBee[®] could have supplied enough dissolved oxygen to meet the BOD reduction needs in the first lagoon, PSI installed two pond circulators. The first lagoon is large enough to produce severe odor events relating to wind changes; two pond circulators were necessary to ensure a faster re-establishment of the odor cap after high wind conditions.

The total surface renewal capacity of each installed pond circulator is about 2,500 gpm (5.57 ft³/s or 0.158 m³/s) at full sunlight. This includes 500 gpm (1.11 ft³/s or 0.031 m³/s) of primary flow, which, in turn, causes an additional 2,000 gpm (4.45 ft³/s or 0.127 m³/s) of induced flow to come up from the lower depths of the pond under the machine, for a total of 2,500 gpm. The height of the intake hose of the pond circulators is flexible and based on the primary application. In this case, since the primary application and goal was odor reduction, PSI set the intake hose at a higher level to create a uniform oxygen cap on the pond in order to destroy hydrogen sulfide vapors.

Based on an actual primary flow of 500 gpm and an estimated pump efficiency of 20 percent, the energy requirements to operate the pump shaft can be calculated as follows:

$$500 \text{ gpm} \times \frac{0.5 \text{ in}}{12 \text{ in/ft}} \div (3960 \times 0.2 \text{ eff}) = 0.026 \text{ hp} = 20 \text{ W} \left(66 \frac{\text{BTU}}{\text{hr}} \right)$$

Assuming a conservative efficiency number of 50 percent for the DC motor and gearbox, the motor needs about 40 Watts of input power to rotate the impeller at full design speed.

Each pond circulator has three Siemens M55 solar PV panels on a triangular pitch rated at 60 Watts (204.8 BTU/hr) nominal output and 50 Watts (170.9 BTU/hr) of actual usable output per PV panel. Due to the triangular mounting configuration, an equivalent of 1.5 panels, or 75 Watts (256.4 BTU/hr), are always exposed to the sun. Ample power is supplied to the pond circulators even in low light conditions. The solar modules supply power to a converter box that powers a 1/8 hp (93.3 W or 318.4 BTU/hr) DC motor and gearbox, which in turn rotates a 24 inch (0.6 meters) impeller at a variable speed of 0-150 rpm. The water intake hose is one foot (0.3 meters) diameter x 20 feet (6.1 meters) long. The circulators thus operate from sunrise to sunset, with an electronic controller regulating the motor speed to obtain optimum pump performance based on power being generated by the PV panels. From sunset to sunrise, the circulators cease to operate unless a separate electric or battery-powered auxiliary kit is also installed with the system. PSI did not select the auxiliary kit in this case because the design was adequate to reduce the odors with daytime operation only.

The Indian Health Services (IHS) handled the procurement of the PV system, representing the Sac & Fox Tribe WWTF and federal regulatory agencies in overseeing the design, engineering and installation. PSI completed the procurement process from receiving system order to system installation in a period of two to three weeks.

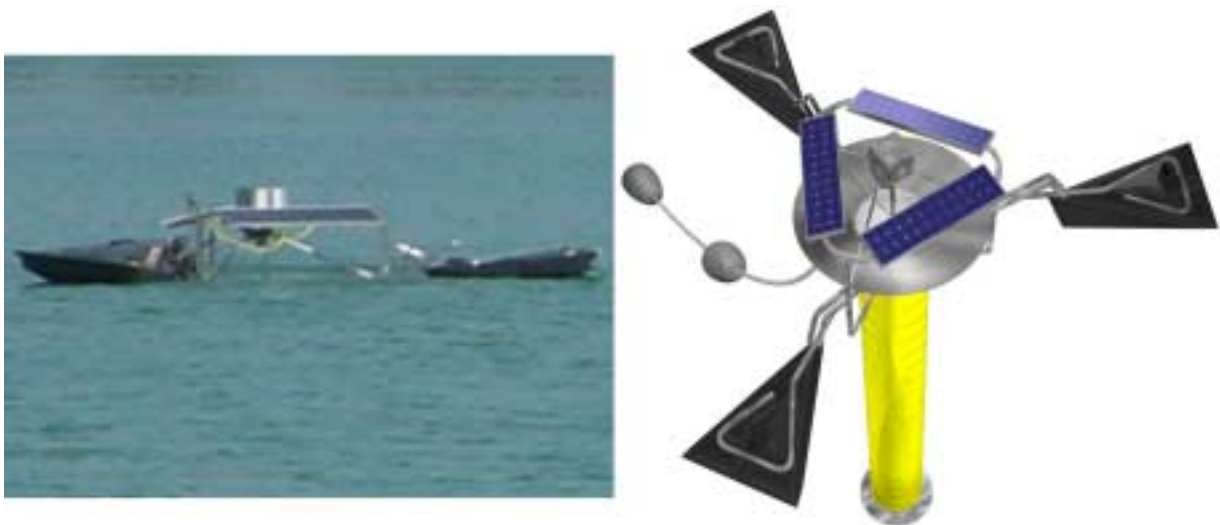
Installation Process

PSI provided two qualified technicians to complete the installation in one day. Each pond circulator unit required two to three hours of field assembly and installation time. The existing WWTF required no modifications because of the installations.

Each pond circulator at the WWTF is 16 feet (4.9 meters) in diameter and weighs 300 lbs (136 kg), excluding the anchors. The PSI technicians anchored the pond circulators using two concrete mooring blocks for each machine. They connected the blocks to each other and the machine with a stainless steel chain about 8-10 times the pond depth. Swivels in the chain prevented any twisting or tangling.

The PSI technicians connected the one foot (0.3 meters) diameter x 20 feet (6.1 meters) long flexible intake hose to the machine through a molded mounting bracket. The other end of the hose has a strainer, with a combination of a float ball and a weight that prevents the strainer from ever settling into the slurry or sludge at the bottom. The distribution dish, mounting bracket and structural members are constructed of stainless steel to prevent any corrosion. Support legs are provided at the bottom of the floating system to allow the circulators to rest on the pond bottom during low water levels. A diagram and picture of the current SolarBee[®] circulators similar to the pond circulators in operation at the WWTF are illustrated below.

Figure 2: Iowa - Pond Circulator



Timeline

The timeline for system order, procurement and system installation is shown in Table 2

Table 2: Iowa - Installation Timeline

Event	Date
Negotiations with Indian Health Services	Late 1999 – Early 2000
Quotation for system	December 1999
Order Placed	February 2000
Installations completed	March 2000

Production Data

Production data for PV applications such as the solar pond circulator are not typically available in terms of the electricity produced by the PV cells. The monitored variables in this case were carbonaceous biological oxygen demand (BOD) and total suspended solids (TSS). The Sac & Fox Tribe WWTF did not measure any data for odor reduction, which was the main objective of the project.

The Sac & Fox Tribe WWTF does not need to test incoming (influent) and outgoing (effluent) water quality on a continuous basis. Testing has been done on a random, non-periodic basis. The data obtained for quality of influent and effluent is impacted significantly by the testing methodology employed. In addition, the constant load changes to influent quality affect the quality of the effluent.

The Indian Health Services (IHS) believes that the SolarBees[®] have helped reduce odor, BOD and TSS. Although elimination of the odors was not achieved immediately after the installation of the units, a noticeable difference was detected after a two to three week period. Approximately two months after installation, very little odor could be detected. The installation of the SolarBees[®] helped keep the Tribe in compliance with the Environmental Protection Agency and their imposed discharge limits.

The Sac & Fox Tribe WWTF is required to meet weekly and monthly restrictions of pH, BOD and TSS in the effluent water quality. The pH is required to be maintained at a level between 6 and 9 at all times. The weekly limits of BOD and TSS in the effluent are 40 mg/l (0.04 kg/m³) and 120 mg/l (0.12 kg/m³), respectively. The monthly limits of BOD and TSS in the effluent are 25 mg/l (0.025 kg/m³) and 80 mg/l (0.08 kg/m³), respectively.

In spite of significant variations in the quality of the influent and changes to wastewater quality in different cells at varying periods of the year, a satisfactory reduction in odor, BOD and TSS was achieved as the pond circulator PV modules worked effectively to power the pump for pond re-circulation.

Financial Incentives

This project did not have any direct financial incentives, except for a 10 percent Federal Business Investment Tax Credit for Qualifying Energy Property. The tax credit is available for commercial and industrial businesses that invest in solar and geothermal energy property and has a limit of \$25,000 per year. This 10 percent tax credit was applied to the cost of the three solar panels in the pond circulators. However, according to Pump Systems Inc., many of their recent installations have qualified for higher tax credits in California. There were no other tax ramifications in this case.

Project Costs

The cost of each circulator was \$22,400. Since four pond circulators were installed in the three lagoons at the WWTF, the system cost was \$89,600. In addition, there was a \$2,500 installation charge for a complete project installed cost of \$92,100. Initially, the circulators units were rented during March 2000 for \$22,500. At the end of the year, they were purchased outright and the rent was applied toward the purchase.



The pond circulators have not had any operating costs. The only maintenance costs have been for the DC motor brushes that have to be replaced annually at a total cost of \$10. The pond circulators are covered by a limited five-year parts and labor warranty.

Energy and Emission Savings

The energy savings for this application were calculated in terms of cost of alternative options to reduce the odor problem at this facility. The most likely alternative option would be use of a grid-connected electric-powered pond aerator. Two levels of aerator options are considered below.

According to PSI estimates, 24-hour operation of an 8 hp (5.97 kW) aerator would be required to produce the same amount of dissolved oxygen as the pond circulators. This is assuming that no mixing takes place in the pond. Based on electricity cost of 6 cents/kWh during the time of installation, the annual energy cost for the dissolved oxygen aerator would be:

$$8hp \times 0.746 \frac{kW}{hp} \times 24 \frac{h}{day} \times 0.06 \frac{\$}{kWh} \times 365 \frac{days}{yr} = \$3,137 / yr$$

According to U.S. Environmental Protection Agency (EPA) estimates, a 1 kW solar PV system installed in Iowa results in annual emissions savings of 3,702 pounds (1,683 kg) of carbon dioxide, 8 pounds (3.64 kg) of nitrogen oxides, and 16 pounds (7.27 kg) of sulfur dioxide. The four pond circulators at the Sac & Fox Tribe WWTF have an installed capacity of 660 W (each machine has three 55W solar panels). This would result in the following annual emission savings:

- 2,443 lbs (= 3,702 lbs x 660W/1000W) of carbon dioxide annually
- 5.3 lbs (=8 lbs x 660W/1000W) of nitrogen oxides annually
- 10.6 lbs (=16 lbs x 660W/1000W) of sulfur dioxide annually

To mix the dissolved oxygen throughout the first two ponds, where virtually all BOD reduction occurs, PSI estimates the total power required by the aerators to be about 175 hp (130.6 kW). This estimate is based on the rule-of-thumb of 10 hp (7.46 kW) of aeration requirement per million gallons ($1.33 \times 10^5 \text{ ft}^3$, $3,785 \text{ m}^3$) of water. Depending on the water depth and based on the above calculation, the annual energy cost for the mixing aerator would be:

$$175hp \times 0.746 \frac{kW}{hp} \times 24 \frac{h}{day} \times 0.06 \frac{\$}{kWh} \times 365 \frac{days}{yr} = \$68,617 / yr$$

The circulators at the Sac & Fox WWTF having displaced about 175 hp (130 kW) of aerator equipment, the emission savings would be considerably higher if the avoided emissions of not installing aerators are considered. In that case the annual emission savings would be approximately:

- 481,260 lbs (= 3,702 lbs x 130 kW) of carbon dioxide annually.
- 1040 lbs (= 8lbs x 130 kW) of nitrogen oxides annually
- 2080 lbs (= 16lbs x 130 kW) of sulfur dioxide annually.

Thus, depending upon the type of aerator, dissolved oxygen or complete mixing, the energy and emission savings would be different. In absence of SolarBees,[®] the complete mixing type of aerator would be the likely alternative for this application. Thus, the emissions and cost savings would be closer to the estimates for the 175 hp machines. Maintenance is usually higher on pond aerators and depends on the type of aerator manufacturer.

Lessons Learned

PSI and the Sac & Fox Tribe WWTF believe that the following lessons were learned from this project:

- Solar powered pond circulators are very effective in odor and BOD control and significantly less energy-intensive than electric pond aerators.
- In the case of very cold climates where the pond circulators freeze into ice, the impeller will still rotate because the impeller shaft is surrounded by an oil-filled polymer tube. In severe cases, the pond circulators freeze without any damage. The effect of freezing on the alternative aeration process is unknown.
- The maintenance costs are significantly lower as compared to an aerator. Typical aerator maintenance costs according to PSI calculations are about \$3,000/yr for 150 hp aeration equipment.

Appendix A: PV Questionnaire

We are pleased to inform you that Black & Veatch has been selected by Iowa Department of Natural Resources to conduct a case study of solar PV applications installed since 1999 in the Midwest. Please provide the following information as part of the study. We thank you for your cooperation. This report will be distributed widely to engineers, at technical workshops and published over the internet to promote solar PV systems.

Project History

- Project Name, Size and type of PV cell, and Owner or final end user with contact information.
- Reason for choice of photovoltaic system as energy source.
- Negotiations conducted with regulatory authorities and utilities.
- Permitting, zoning and all other applications that were filed.
- Other activities preceding project construction.

Design and Procurement Process

- Selection of type of photovoltaic system among various alternatives.
- System (PV and inverter) sizing procedure, one-line electrical wiring diagram and instrumentation details.
- Who was responsible for sizing the system?
- Procurement process and system delivery time-table including major milestones.

Installation Process

- Installation schedule.
- Capital costs.
- Major hardware components including any tracking system used for installation.
- Ease of finding qualified contractors to do the installation.
- Could the end-user have assembled (direction, azimuth, elevation, wiring, mechanical assembly, etc?) the system by themselves with adequate instructions?
- Lessons learned during construction that can be applied to future projects.

Timeline

- Process time-line from initial vision, system engineering, procurement, installation and start-up.

Operations Costs

- Annual cost of operating and maintaining the system.
- System reliability and major problems faced with operation and maintenance.
- How many times was routine maintenance required annually and is routine maintenance possible by the owner themselves?

Production Data

- Please provide electric production (or water pumping) data or performance summary for any consecutive 12-month period since 1999 to verify system reliability.

Electrical Consumption

- What is the ratio of electricity consumption for the load served by the photovoltaic system against the total electricity produced by the system?
- Applications for which PV-produced electricity was used.

Financial Incentives / Energy and Cost Savings / Economic Analysis

- Financial incentives considered while undertaking project development and other activities preceding project construction.
- Summary of annual energy, monetary and emission savings.
- Tax ramifications/benefits.

Environmental Issues

Environmental issues surrounding operation and maintenance of the photovoltaic system.